

Metamaterials for Advanced Visible and Ultraviolet Optical Components (Metamaterials)

Completed Technology Project (2016 - 2018)



Project Introduction

Metamaterials are artificial electromagnetic media nanostructured on a scale much shorter than their operating wavelength, having effective optical properties not found in nature. In particular, their effective permittivity and permeability can, under certain conditions, be separately controlled, and can be negative. Thus refractive index $n = \pm(\epsilon\mu)^{1/2}$ can also be selected (including values less than 1), giving substantial control over the wavefront of propagating light. Traditional refractive optics uses materials with differing refractive indices to accumulate phase shifts during propagation of light and direct it in desired directions. Metamaterials need not depend on this accumulated phase change, and provide methods for creating abrupt phase jumps.

Traditional optical components rely on conventional materials and structures whose properties limit their effectiveness in certain wavelength ranges. In particular, UV optics suffers from a lack of high-efficiency reflective and transmissive materials and components. Artificially structured metamaterials offer the possibility for new design concepts that were not previously available, such as the use of plasmonic resonances and the ability to match to the impedance of free space. These new structures hold great promise for overcoming the limiting UV properties of traditional materials.

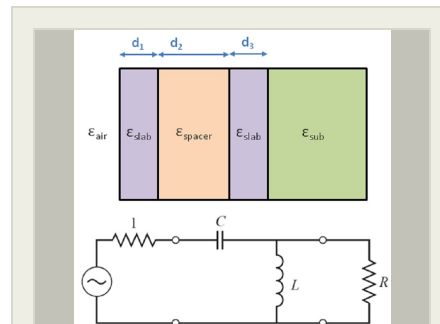
One exciting aspect of the wavefront-shaping capabilities of metamaterials is that they can be engineered for different wavelength regimes, extending to THz and microwave frequencies. The wide range wavelength selectivity of metamaterials broadens their scope of applicability, with respect to both wavelength range and mission target, into a strongly crosscutting technology.

Because of losses in UV optics, total system throughput of current instruments can be low, due to interactions with multiple optical surfaces. LiF on aluminum reflectors is one of the best current solutions, producing 60% reflectance from 100-115 nm, but this is still quite low. For instance, 60% reflection from each of a series of five optical surfaces produces a final intensity of 8% relative to the incoming light. Therefore, even a modest improvement in the efficiency of each of these surfaces can produce a dramatic improvement in overall throughput.

Due to the complexity of fabricating three-dimensional metamaterials, "metasurfaces" have received a great deal of attention. These are thin quasi-2D optical structures that enable many of the capabilities of their 3D counterparts. One new area utilizing these metasurfaces is "metatronics" in which nanostructures play the role of optical lumped circuit elements.

Metatronic components can be used to design optical filters, the focus of this work.

Our objectives focus on two technologies: (i) "Optical circuits" implemented with thin films and (ii) metasurfaces implemented with resonant optical scatterers. Metatronic thin-film optical circuits utilize layers much thinner than



Circuit representation for optical response of metal (purple) and dielectric (orange) filter structure.

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the wavelength, and can be designed for either reflective or transmissive mode operation. They produce phase shifts of light upon reflection or transmission at the boundaries, enabling nanometer-thin films to substantially modify the light spectrum. Thus these materials provide new optical properties and functionalities. The individual metallic or dielectric layers behave as shunt inductors or capacitors, respectively. Response of the multilayer structure can be derived from the action of these elements to incoming light. Therefore filter elements can be designed with a desired response by combining the elements according to electronic filter design methods.

Our second focus, arrays of optical scatterers use resonances associated with surface plasmons to control the phase of scattered waves. By proper control of materials and geometry, frequency-selective wavefront control is possible. Metasurfaces using arrays of optical scatterers with subwavelength separation produce a tailored optical response. Large and controllable changes of the optical properties are achieved through interaction with these scatterers. This enables engineering of amplitude, phase, and polarization response.

Subwavelength resolution makes it possible to funnel incident optical power into a single beam while eliminating other diffraction orders. This avoids a fundamental limitation of diffractive optical components, which typically produce multiple diffraction orders.

Anticipated Benefits

UV science is vital for astrophysics (e.g. stars, galaxies, exoplanets, and intergalactic medium), planetary science (atmospheres, aurorae, mineralogy), and heliophysics. The UV spectrum is rich with information but is underutilized, in part because of a lack of suitable optical materials and devices. High-efficiency optical components, including filters and mirrors, are not readily available in the shorter UV wavelength ranges. Current materials provide low system throughput and low (or no) out-of-band rejection.

This work addresses these limitations, by using optical metamaterials to provide new solutions to the problem of UV optical components. Development of revolutionary new components and instruments using metamaterials would provide a critical advantage in optics systems with lower mass, lower complexity, and higher throughput.

Defense agencies use UV detection for applications such as covert communication and flame sensing. This technology will enhance UV detector capabilities while reducing the size and mass of components for these applications.

Organizational Responsibility

Responsible Mission Directorate:

Mission Support Directorate (MSD)

Lead Center / Facility:

Jet Propulsion Laboratory (JPL)

Responsible Program:

Center Independent Research & Development: JPL IRAD

Project Management

Program Manager:

Fred Y Hadaegh

Project Manager:

Fred Y Hadaegh

Principal Investigator:

Douglas Bell

Co-Investigators:

Nader Engheta

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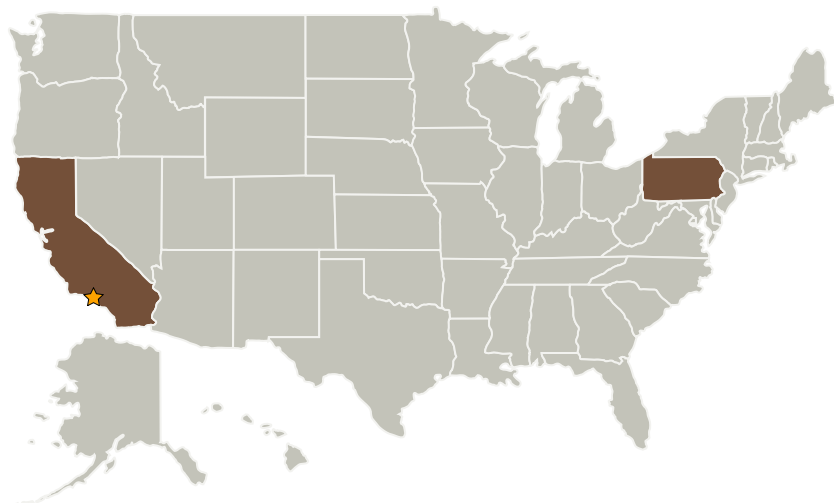
Shouleh Nikzad

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Primary U.S. Work Locations and Key Partners

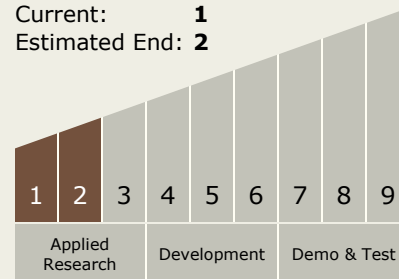


Organizations Performing Work	Role	Type	Location
★ Jet Propulsion Laboratory (JPL)	Lead Organization	NASA Center	Pasadena, California

Primary U.S. Work Locations	
California	Pennsylvania

Technology Maturity (TRL)

Start: **1**
 Current: **1**
 Estimated End: **2**



Technology Areas

Primary:

- TX08 Sensors and Instruments
 - TX08.2 Observatories
 - TX08.2.1 Mirror Systems

Target Destination

Foundational Knowledge

Supported Mission

Type

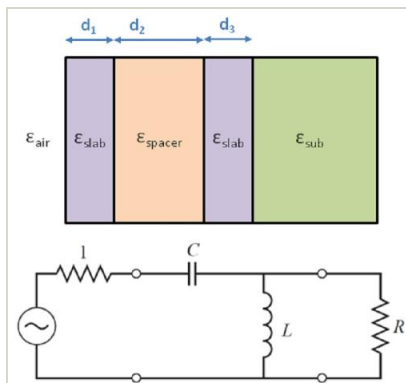
Push

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Images



JPL_IRAD_Activities Project Image

Circuit representation for optical response of metal (purple) and dielectric (orange) filter structure. (<https://techport.nasa.gov/image/27872>)